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AERO-STRUCTURAL OPTIMIZATION OF AIRCRAFT WING BY FINITE ELEMENT METHOD

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ABSTRACT

New and innovative designs must be explored to meet the aircraft requirements lower weight and more cost effective structure for future airplanes. For these reasons, present study aims to deals with the structural analysis for predicting the structural behavior of aircraft wing with ribs and stringers. With an helpful of aerodynamic principles, aircraft wing with ribs and stringers were analyzed by considering two criteria, one is varying load conditions and the other method is varying structural materials. For structural and aero–elastic response analysis, finite element method is used in ANSYS software with efficient computation. Wing behavior of total deformation (δ) , equivalent (von Mises) stress (σ_v), equivalent elastic strain (ε), ultimate tensile stress (UTS) and wing twist to be simulated. From the computational results, better performance aircraft structure material, in terms of light weight, low fuel consumption and cost-benefit to save economy is identified.

***KEYWORDS** Aircraft Wing Optimization, Modeling and Simulation, Finite Element Method, & ANSYS*

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Original Article

INTRODUCTION

Innovations must be made in the design for the interface requirements of the nose landing gear, the wise fuselage interface structure, the flight station, the empennage and so on. These multifaceted requirements results in severe restrictions on the basic configuration of the shell and also the structural-material concepts selected for use in its design. Considerable weight saving potential is to be proven with the application of composite materials to the fuselage of commercial transports.

Constraints and suitable loads are applied on the initial design space of the component for analyze nonparametric topology optimization method on a aircraft vertical stabilizer component by using ANSYS software. CAD geometry model is converted into FE optimized model by using CATIA software. An analytical model of fiber reinforced open cracked composite wing vibrating in coupled bending torsion in unmanned aerial vehicles-UAV's was studied[1]. The frequency variation was fully controlled and less sensitive measurement errors attained by torsion or bending mode in Cawly Adams criterion method. Torsion and bending are essentially decoupled, if there is no crack, for fiber angle is in 0° or ± 90° [2,3].

Meanwhile single level optimization is more efficient and feasible for a wing design, when compared to two level optimization [4]. The numerical studies of composite T- joints, which is located at the spar – lower skin joint section in aircraft wings with carbon fibre (CF) materials. For determine strength and study the behavior of T-joints , pull out force is applied on the top of the web [5]. The development of composite wing, by using higher

order theory, for efficient and accurate estimation of both static and dynamic responses. A hybrid design optimization techniques is proposed by box beam analysis, with an integrated of aeroelastic analysis [6]. The combined for structural and aerodynamic optimization of a high speed civil transport wing by using WINGDES code aerodynamic design. ASTROS tool was used to perform a FE based structural optimization of wing box. The procedure provides the missing link and information, between aerodynamic and structural optimization procedures developed at the ASDL [7].

The carbon fiber reinforced plastics-CFRP contribute structural mass of an aircraft for more than 50% of both military and civil aircrafts, UAV's, space launchers and satellites [8]. Radar cross section -RCS, scramjet/airframe integration, trimmed characteristic, aero heating ,aero dynamics, static structural and maneuverability at cruise stage was computed and determined. When compared to basic configurations pareto solutions, with integrated for pareto front side obtained excellent performances [9]. Hypersonic flow, about a swept parabolic body with direct numerical simulations-DNS. Meanwhile, novel approaches like DNS based global stability theory of flow configuration, represents a more realistic models. Combining numerical simulations with advanced iteration techniques are confidentially recommended, for analyzing governing physical process of complex flows [10].

Composite materials have demonstrated significant weight savings for aircraft structures with the extra advantages of outstanding corrosion and fatigue damage resistance. Apart from these advantages, the potential benefits of composite aircraft primary structures have been limited by the labor intensive manufacturing processes, and inadequate technology in structural mechanics and material science[11]. For a safe design it is difficult to understand the behavior of these structures under compression and to predict the ultimate strength. The design of a composite fuselage must provide the necessary strength and rigidity to withstand the loads and also environment that it will be subjected during the operational life of the aircraft. In our research study, analysis was conducted for structural characteristics of aluminum (Al) alloy (Al-5Si) material versus composite materials. The wing model of NACA 2215 series with 5 ribs excluding tip and root ribs and 8 stringers were designed using CATIAV5 R20 and was developed in ANSYS Software packages (version 14.0) by using finite element method. The applied loads are ranging from 1kg to 11 kg and the considered here for analyzing the study materials are aluminum alloy(Al-5Si)-M_1, carbon fiber-CF-M_2, E-glass-M_3 and Kevlar-M_4. Our research paper finds which material exhibits better structural characteristics and helps to improve the structural performances of aircraft wing.

AEROSTRUCTURAL DESIGN PROBLEM FORMULATION

The physical structure modeled in this work is a rectangular aircraft wing of cross section NACA2215 series and is modeled using CATIA V5R20 software packages is shown in Figure. 1.

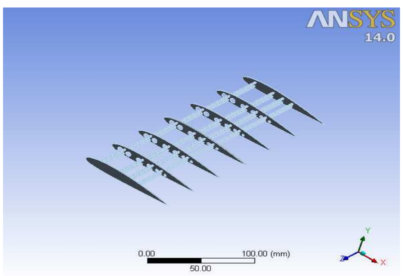


Figure.1 Design Model of Aircraft Wing with Ribs and Stringers

The chord length at the free end and the fixed end are same and is 100mm and the length of the wing is 240mm. There are six numbers of ribs and eight numbers of I-shaped stringers are placed. The ribs are placed along the span wise at

an interval of 40mm. The created model was developed in ANSYS 14.0, it has 30325 elements, 58379 nodes and then static structural analysis were done under various loading conditions and for conventional and various composite materials. Table 1 shows the structural design boundary conditions of A400M airlifter wing for simulation . For static structural analysis the wing is treated as cantilever beam and is fixed at one end and the load is applied at another end in vertical direction. Depends upon the chemical composition and mechanical properties, strength and stiffness varies for each material . The boundary conditions of mechanical properties for M_1, M_2, M_3, M_4 is illustrated in Table 2. By using these study material properties of input data, accurate results will be obtained from ANSYS simulation.

Table 1: A400M Airlifter Wing Structural Design Boundary Conditions for Simulation

S.I	Parameter	Dimensions
1	Design pay load	38050 kg
2	Operating empty weight (OEW)	76500 kg
3	Mach Number for cruise	0.85
4	Fixed design mass	85200 kg
5	Wing span	42.4 m
6	Initial wing offset mass	25000kg
7	Thrust specific fuel consumption (TSFC)	0.53 lb/hr
8	Maximum takeoff weight	141,000kg
9	Fuel Capacity	50,500 kg
10	Maximum landing weight design	122,000kg
11	Thickness to Chord length (t/c) linearity	7

Table 2: Boundary Conditions of Study Material Properties for Wing Simulations Using Ansys

Material Description	Material Types	Structural properties		
		Young's Modulus (E) in Gpa	Poisson's Ratio (ν)	Bulk Modulus (K) in Gpa
M_1	Al Alloy(Al-5Si)	71	0.33	69.608
M_2	Carbon Fiber	135	0.3	112.5
M_3	E-Glass	40	0.25	26.667
M_4	Kevlar	75	0.34	78.125

RESULTS AND DISCUSSIONS

Aerostructural Simulation Contours

Deformation of wing influences change in temperature, due to external, gravity, electromagnetic and body forces. The analysis on deflection of wing is much more important so it should be done. Total deformation analysis is simulated by using the Finite Element model of wing shown in Figure. 1 . The Contours presented here are for its self loading conditions (F=1kg). Figure. 2 shows the deflection pattern for case-1 of using M_1, M_2, M_3, M_4 . From the contours Figure. 2(a-d) shows that the deformation value is higher for E-glass varies from 0.00 to 10.273, and lower for carbon fiber varies from 0.00 to 3.0556. Stress plays major role in aircraft wing analysis for withstand various aerodynamic pressure

coefficients.

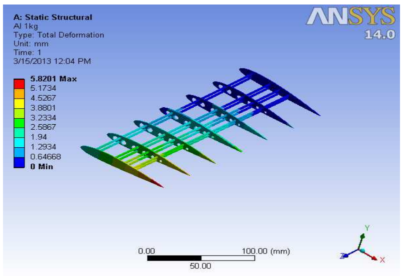


Figure 2(a): Deflection *(δ)* contour for case 1 Al alloy

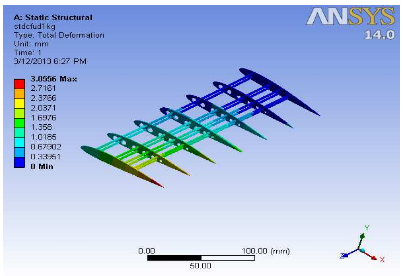


Figure.2(b): Deflection *(δ)* Contour for Carbon fiber

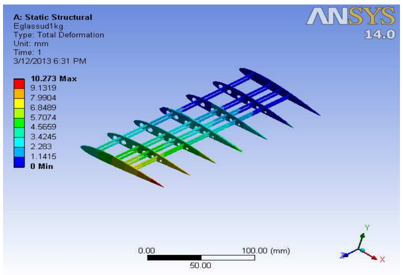


Figure.2(c): Deflection *(δ)* Contour for Case 1E-Glass

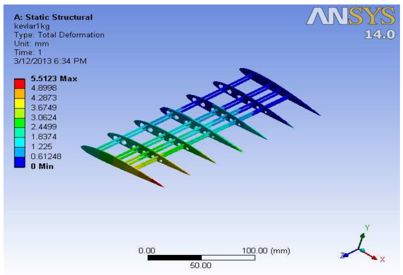


Figure 2(d): Deflection *(δ)* Contour for Case 1Kevlar Materials

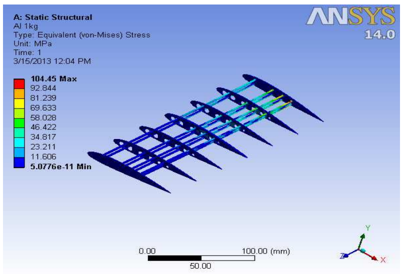


Figure 3(a): Von-Mises stress *(σ_v)* For Case 1 for Al Alloy

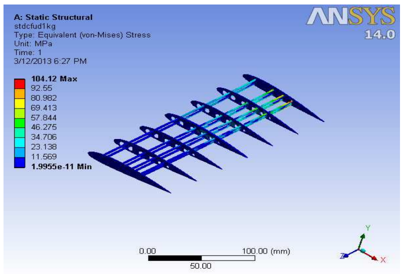


Figure 3(b): Von-Mises Stress *(σ_v)* for Case 1 for Carbon Fiber,

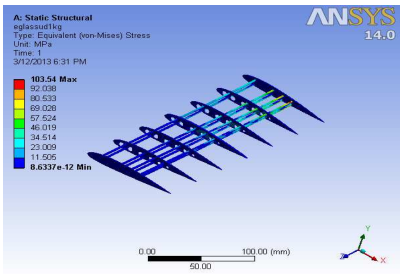


Figure 3(c): Von-Mises stress *(σ_v)* Contour for Case 1 E-Glass

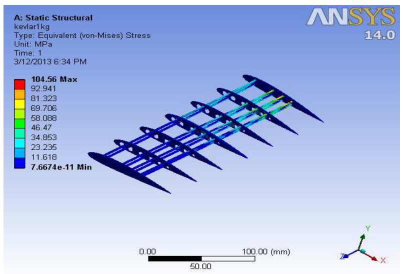
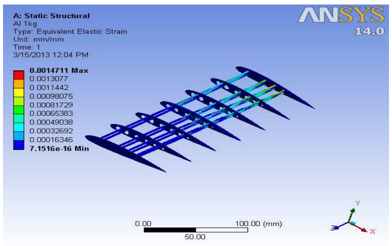


Figure 3(d): Von-Mises stress *(σ_v)* Contour for Case 1 Kevlar Material

The equivalent von-mises stress pattern in case-1 of using M_1, M_2, M_3, M_4 is illustrated in Figure. 3. From the von-mises contour simulation outputs shown in Figure 3(a-d) it is clear that, the stress value is higher for E-glass varies from 8.6337e-12 to 103.54, and lower for carbon fiber varies from 1.9955e-11 to 104.12.

Figure. 4 shows the equivalent elastic strain pattern in case-1 of using M_1, M_2, M_3, M_4. From the equivalent elastic strain simulation contours Figure. 4(a-d), it is cleared that the strain value is higher for E-glass varies from 1.0223e-

15 to 0.0013941, and lower for carbon fiber varies from 1.4782e-16 to 0.00077125.



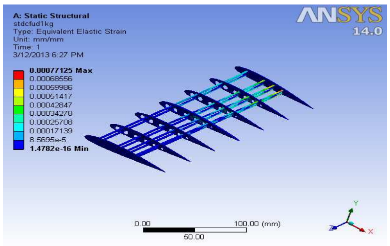
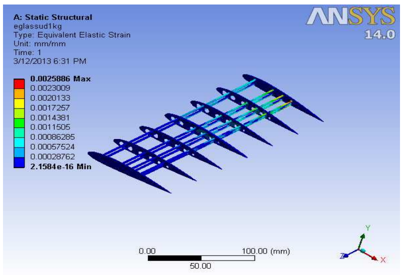


Figure 4(a): Equivalent Elastic Strain *(ε)* for Case 1 Al Alloy

Figure 4(b)Equivalent Elastic Strain *(ε)* for Case 1 Carbon Fiber



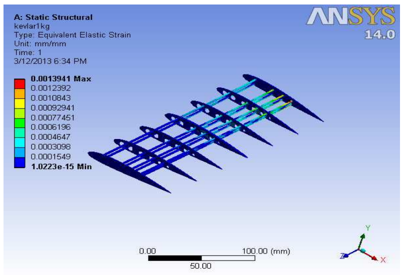
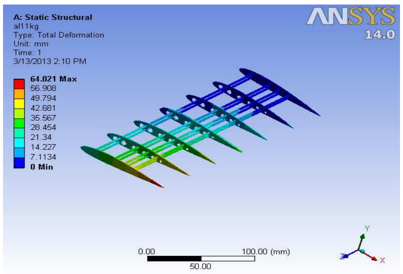


Figure 4(c): Equivalent Elastic Strain *(ε)* Contour for case 1 E-Glass

Figure 4(d): Equivalent elastic strain *(ε)* Contour for Case 1 Kevlar

The deflection pattern in case-2 of using M_1, M_2, M_3, M_4 is illustrated in Figure. 5. These figures are for F=11kg loading conditions. The contours output Figure. 5(a-d), It was concluded that the deformation value is higher for E-glass varies from 0.00 to 113.01, and lower for carbon fiber varies from 0.00 to 33.611.



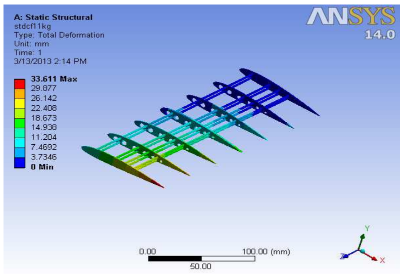
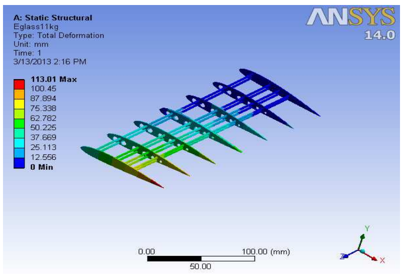


Figure 5(a): Deflection *(δ)* contour for case 2, a Al alloy material

Figure 5(b): Deflection *(δ)* contour for case 2 Carbon fiber



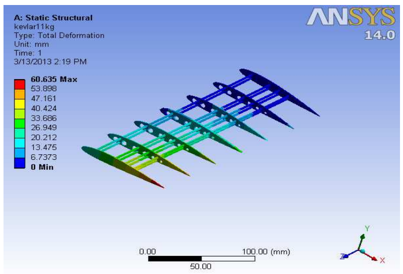


Figure 5(c): Deflection *(δ)* contour for case 2 E-glass material

Figure.5(d): Deflection *(δ)* Contour for Case 2 Kevlar Material

The equivalent (Von-Mises) stress pattern in case-2 of using M_1, M_2, M_3, M_4 is illustrated in Figure. 6. From the von Mises stress *(σ_v)* contours outputs Figure 6(a-d) it is clear that, the stress value is higher for E-glass varies from 9.4971e-11 to 1139, and lower for carbon fiber varies from 2.1951e-10 to 1145.3.

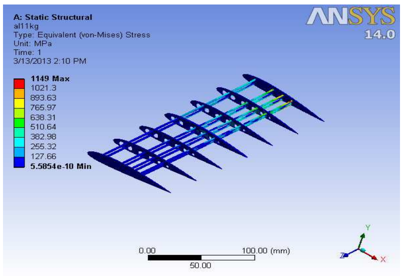


Figure 6(a): Von-Mises stress *(σ_v)* Contour for Case 2, Al Alloy,

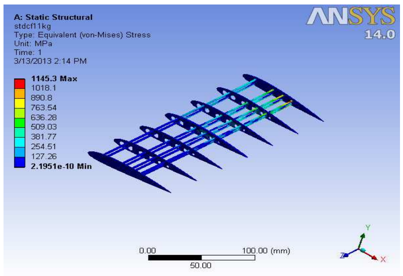


Figure 6(b): Von-Mises Stress *(σ_v)* Contour for Case 2, Carbon Fiber

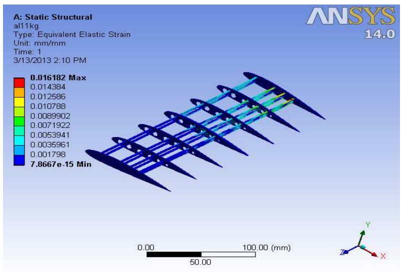


Figure 6(c): Von-Mises Stress *(σ_v)* Contour for Case 2, E-Glass

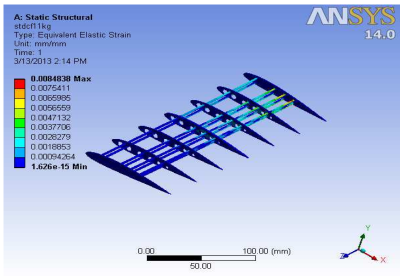


Figure 6(d): Von-Mises stress *(σ_v)* Contour for Case 2 Kevlar Materials

The equivalent elastic strain pattern in case-2 of using M_1, M_2, M_3, M_4 is illustrated in Figure. 7. From the contours and equivalent elastic strain Figure. 7(a-d), it is concluded that, the strain value is higher for E-glass varies from 2.3743e-15 to 0.028474, and lower for carbon fiber varies from 1.626e-15 to 0.0084838.

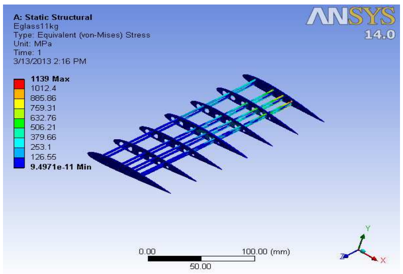


Figure 7(a): Equivalent Elastic Strain *(ε)* Contour for Case 2, Al alloy

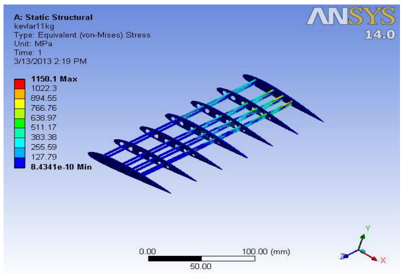


Figure 7(b)Equivalent Elastic Strain *(ε)*Contour for Case 2,CF

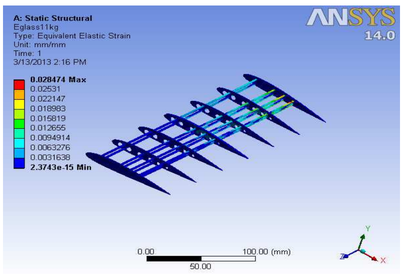


Figure 7(c): Equivalent elastic strain *(ε)* contour for Case 2,E-glass

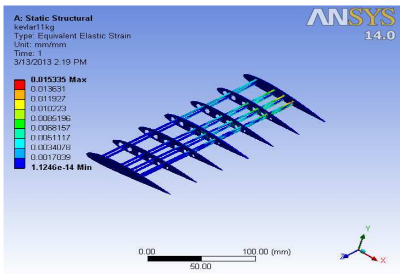


Figure 7(d): Equivalent elastic strain *(ε)* contour for Case 2, Kevlar

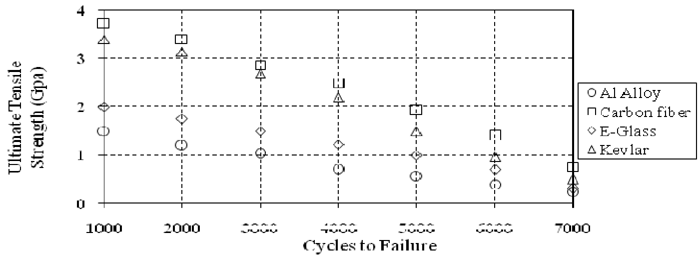


Figure 8: Graphical Representation of Ultimate Tensile Strength (UTS) Comparison Results for our Research Study Materials

Aerostructural Properties

Computation is successfully done by using ANSYS package processed with an computer system configurations of 8GB RAM, Intel core i-9 processor, 2.4 clock speed, with an total running time of 63 Hours for the structural characteristics of wing in response to various static structural loading conditions (F=1,2,3,…..11 kg). Computation results shows the deflection, equivalent stress and elastic strain (from ANSYS package simulation, for wing structure optimization. Total deformation value results and contour (see Figure. 2 and Figure.5), it is clearly concluded that, CF exhibits less deformation *(δ)*, kevlar material exhibits higher deformation than CF, Al alloy (Al-5Si) material exhibits slightly higher than Kevlar and E-glass shows more deformation (nearly the double of Al alloy (Al-5Si) material deformation values). It is precisely concluded that, Al alloy influences von mises stress (σ_v) in comparison with the CF, E-glass exhibits less stress when compared to other three materials and Kevlar, shows slightly higher than Al alloy(Figure. 3 and Figure. 6). it is cleared that Al alloy (Al-5Si) experiences more equivalent elastic strain *(ε),* in comparison with the CF, E-glass shows moderately higher strain than Al alloy (Al-5Si) and kevlar shows little bit of less strain, when compared to Al alloy(Al-5Si) (Figure. 4 and Figure 7) [8], by considering the aerodynamic principles, ultimate tensile strength (UTS) is computed ranges from 1000 to 7000 cycles of wing failure. The performances of take-off gross weight (TOGW), fuel burn and specific mass parameters for all weighting parameter (β) are extrapolated, with the analytical method by connecting contours of von mises stresses, deformation etc. The simulation results output of UTS is shown in Figure. 8. It shows UTS is directly proportional to wing deflection, stress and strain. For each 1000 cycles of operation, the UTS values of wing is gradually decreased for all materials. Observed UTS for M_1 varies from 1.5 to 0.25 Gpa, M_2 varies from 3.74 to 0.76 Gpa, M_3 ranges from 2 to 0.31 Gpa, M4 ranges from 3.4 to 0.5 Gpa. It is clear that, UTS values are also lower for aluminium material and higher for CF.

CONCLUSIONS

A400M military aircraft wing model, as per the configuration is made and the static structural analysis of the wing has been done using ANSYS software package (version 14.0). It shows the total deformation *(δ)* of carbon fiber results is less, when compared with Al alloy (Al-5Si). Meanwhile, von Mises stress (σ_v) value of carbon fiber is better than Kevlar. Carbon fiber experiences less equivalent elastic strain *(ε),* in comparison with Al alloy (Al-5Si). Maximum ultimate tensile stress (UTS) is also observed that, lower for Al alloy material and higher for CF fuel burn and structural mass for parameter function β, with full mass of the wing for the comparison of CF with Al alloy. From CF wing trend, TOGW and fuel burn vary between 250000kg and 85000kg, respectively, for β=0 to 266000kg and 75000kg, respectively for β=1. From CF–Al MMC wing trend, take-off gross weight (TOGW) and fuel burn vary between 230000kg and 77000kg, respectively for β=0 to 238000kg and 64000kg, respectively, for β=1. The structural weight for CF varies from 15000kg, for

β=0 to 29000 kg for β=1. The weight of the CF MMC's wings is between 40% to 45%, lighter than the equivalent Carbon Fibre wing. The TOGW of the CF wings are between 14% to 18%, lighter than the equivalent CF wing. CF nano composite material shows better results, while the other materials are less efficient. It clearly shows under various circumstances of β values, in practical carbon nano tubes, with reinforced Al metal matrix composite material as high reliability, lower life cycle costs, low fuel consumption and higher efficiency can be easily achieved. Reduced weight structure by drastically, if 85% of the A400M's wing structure is made of carbon fiber composites. At the same time, it can handle heavy and outsize loads, combined strategic and tactical capabilities. Compared to CF, Al alloy should be achieved better electro –mechanical properties of UTS, better thermal conductivity of >2000 W/mk, good coefficient of thermal expansion of -1 ppm/k isotropic and best electrical resistivity of <0.1 micro-ohm-m. It is desirable to use CF, for aerodynamic applications, with excellent state-of-the-art technology and state-of-the-art wing for attaining better benefits like high speed, high altitude and performance.

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